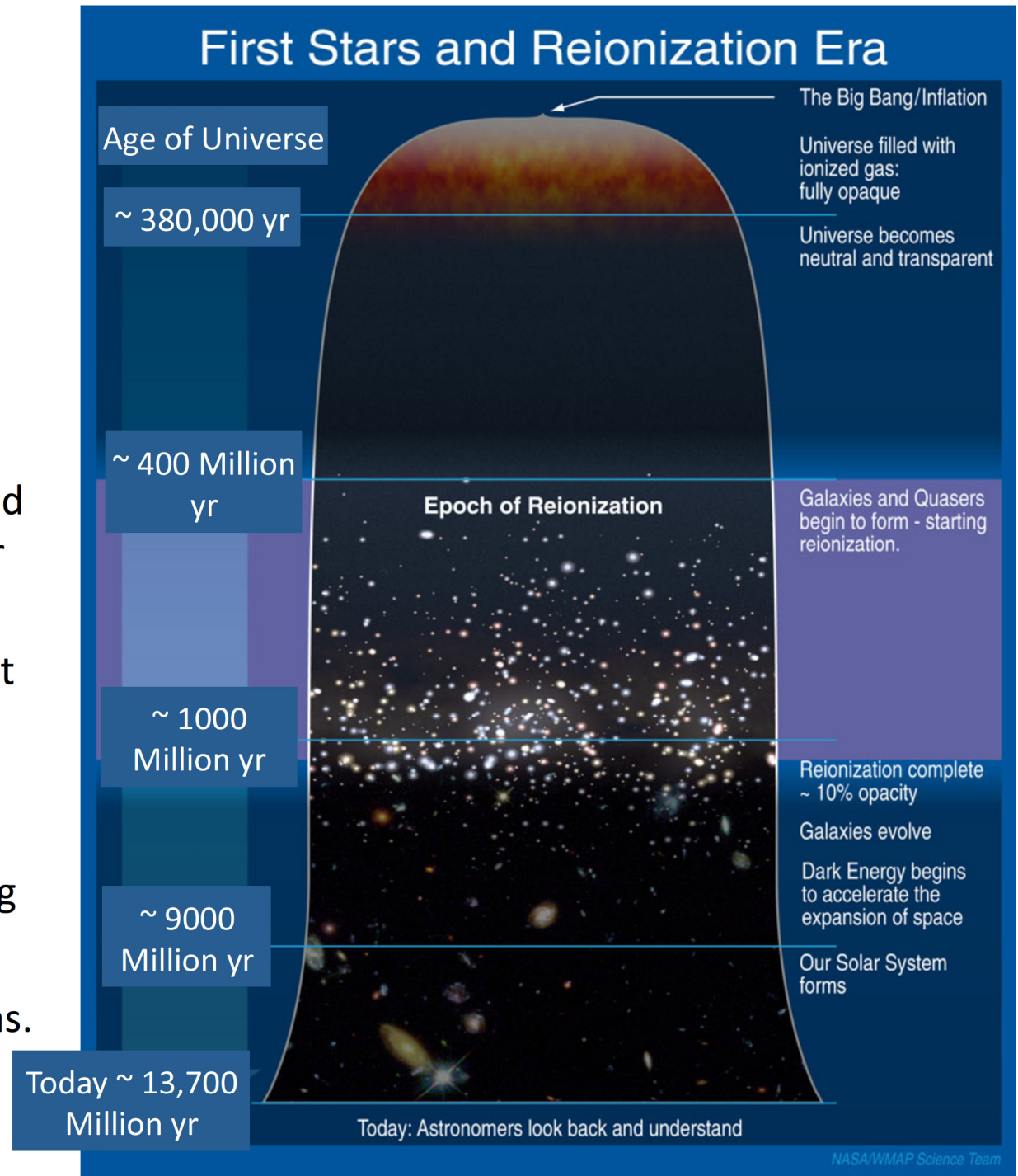


When did the first stars form?

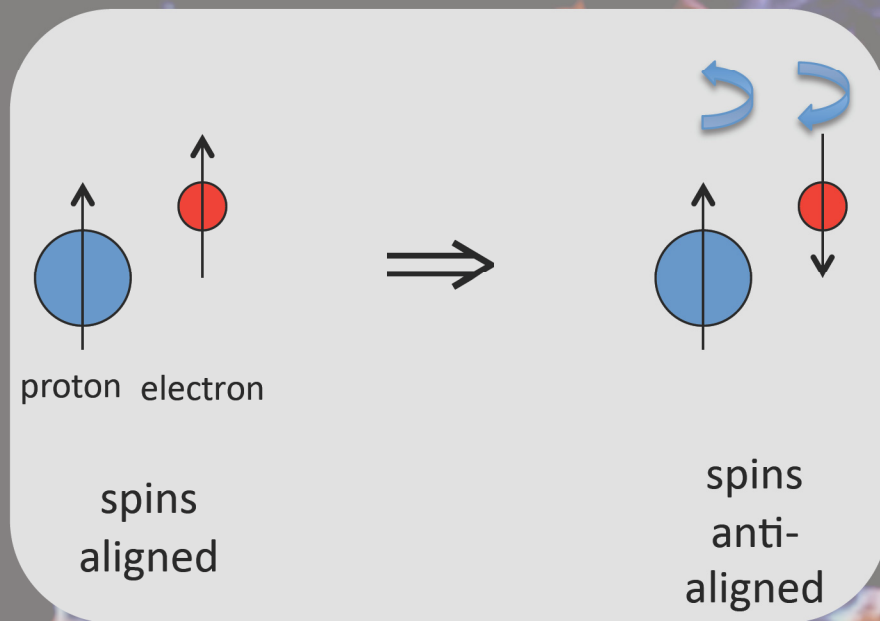
The First Stars and Galaxies

What we know (or think we know) from optical and mm-wave observations ...

- Many galaxies being detected by about 750 Million yr after Big Bang
- An exploding star seen about 600 Million yr after Big Bang
- Indirect measurement suggesting lots of stars by about 500 Million yr after Big Bang
- Stars form from hydrogen gas.



Hydrogen Atom



Change to/from aligned to anti-aligned state produces radio radiation

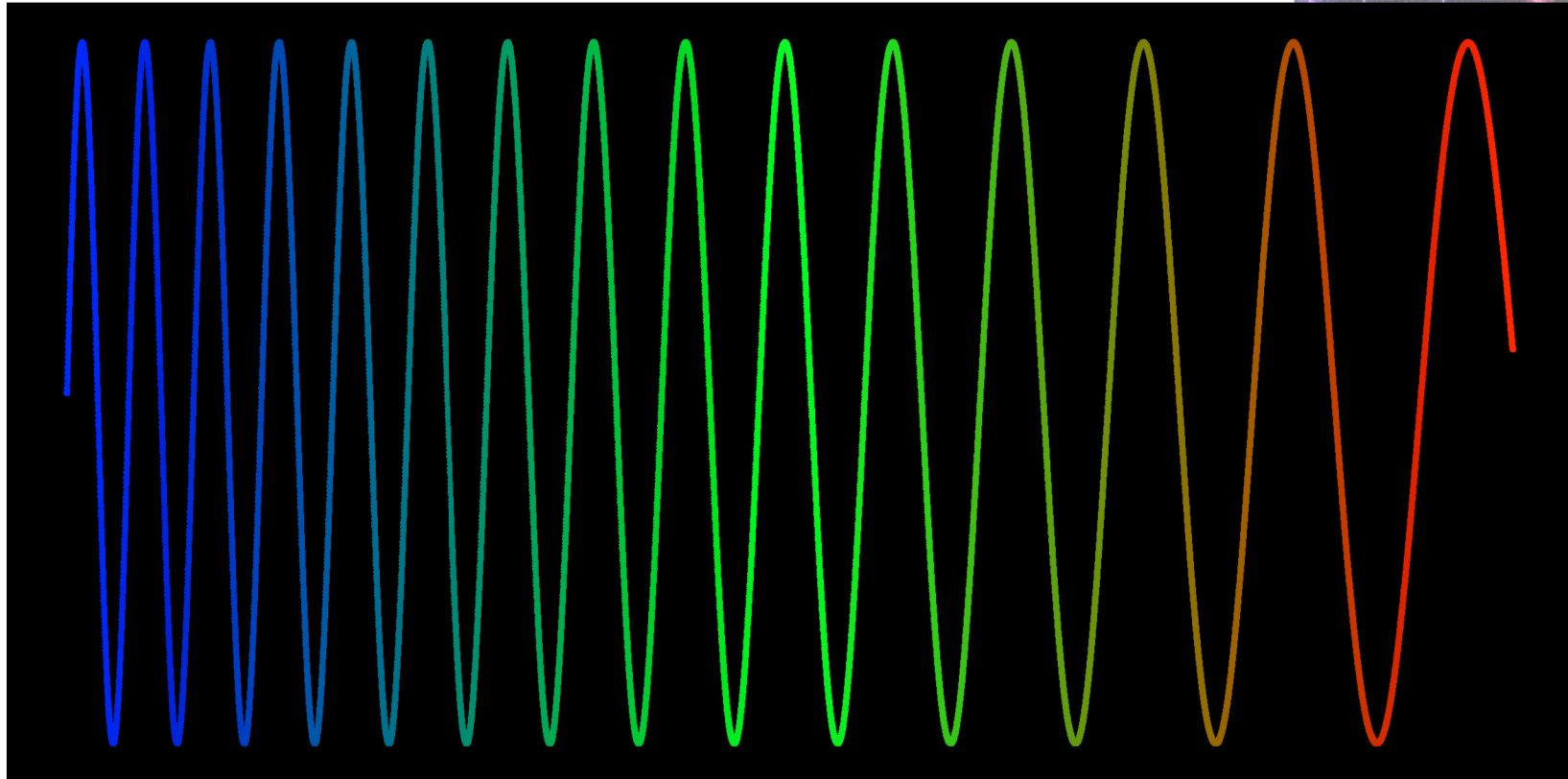
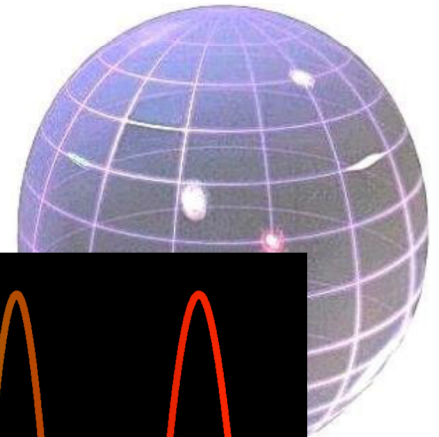
$$\nu = 1420.405752 \text{ MHz}$$

$$\lambda = 21 \text{ cm}$$

	MOBILE **	FIXED	1395
	LAND MOBILE		1400
RADIO ASTRONOMY	EARTH EXPL SAT (Passive)	SPACE RESEARCH (Passive)	1427
	LAND MOBILE	Fixed (TLM)	1429.5
	LAND MOBILE (TLM)	FIXED (TLM)	1430

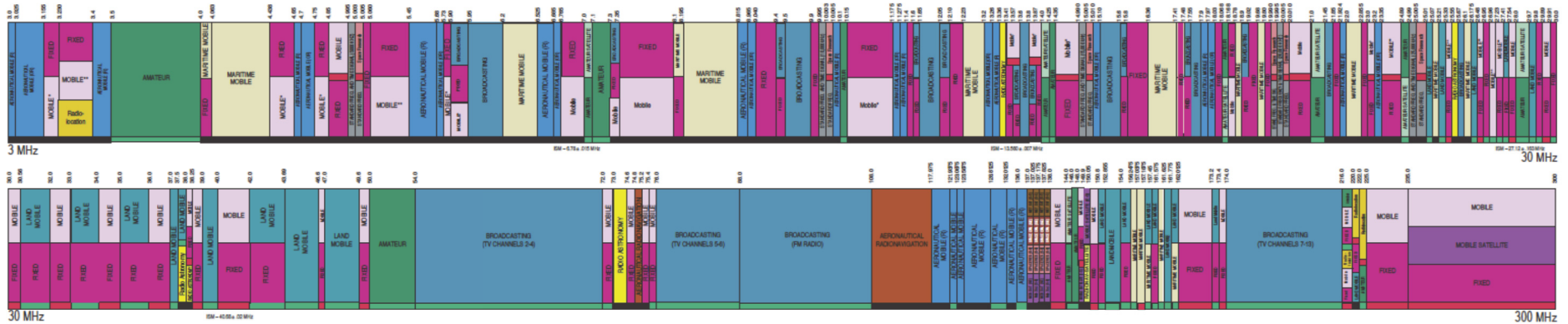


Universal Expansion and Redshift



- Universe is expanding ...
i.e., distances between galaxies increases with time.
- Wavelength of radiation increases as radiation travels through expanding Universe.

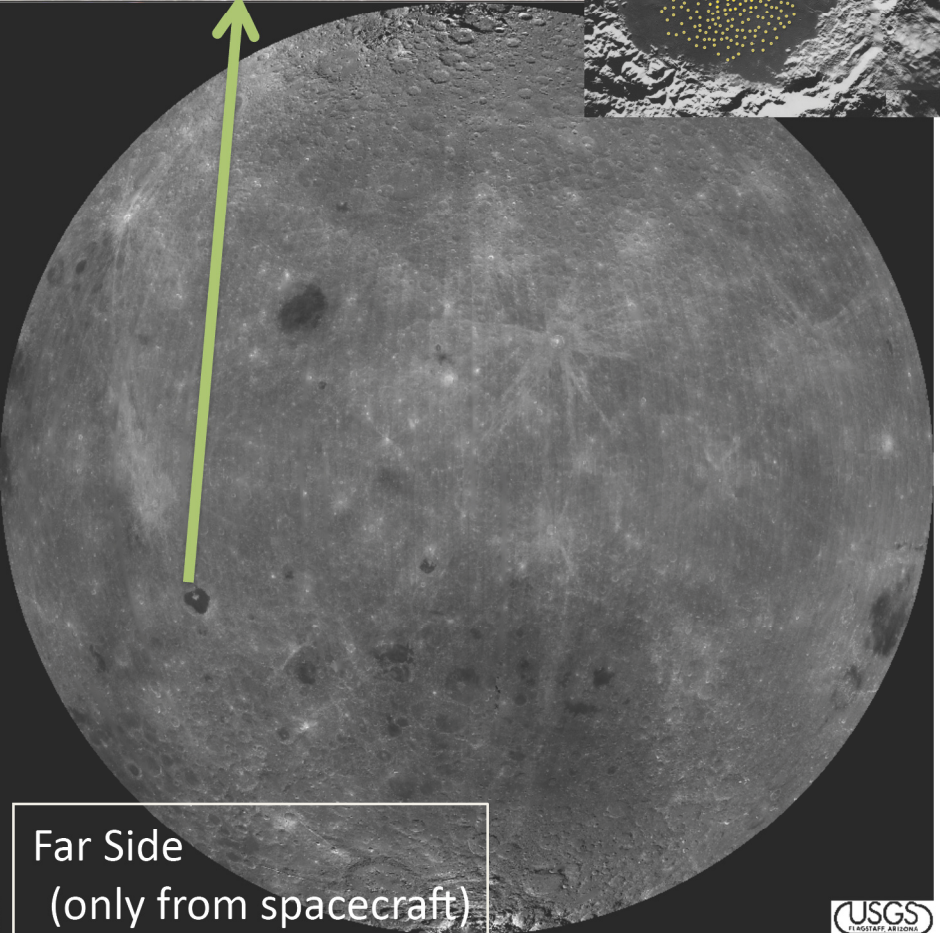
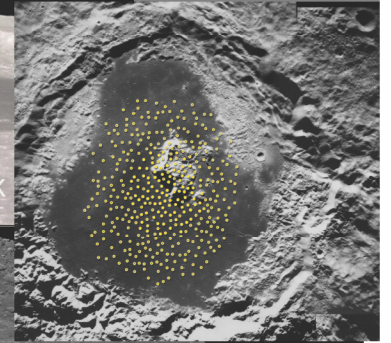
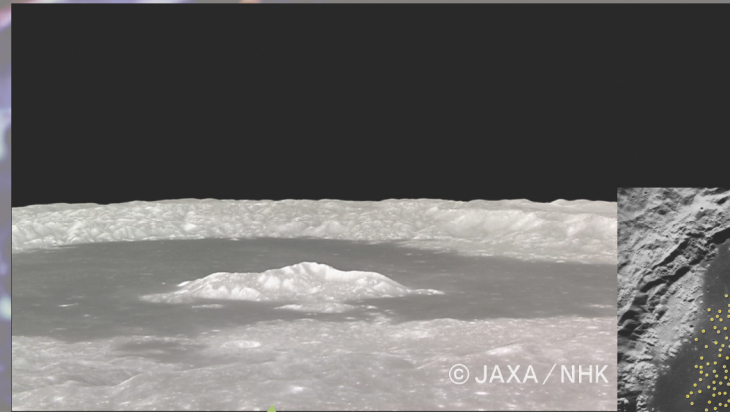
Radio Astronomy Service and Cosmology



Radio astronomy service allocations at

- 73 MHz–74.6 MHz = about 200 Million yr after Big Bang ($z \sim 18$)
 - 37.5 MHz–38.25 MHz = about 75 Million yr after Big Bang ($z \sim 35$)
 - 25.55 MHz–25.67 MHz = about 40 Million yr after Big Bang ($z \sim 55$)
 - [First stars predicted to start forming about 20 Million yr after Big Bang ($z \sim 60$).]
 - 13.36 MHz–13.41 MHz = about 15 Million yr after Big Bang ($z \sim 105$)
- [Observing the Universe **before** the first stars!]

Radio Telescope in Shielded Zone of the Moon ITU-R RA.479



Cosmic Dawn and the Radio Spectrum

Understanding the formation of the first stars, first accreting black holes, and first galaxies requires

- Microwave, infrared, and X-ray telescopes in space, with communication to them;
 - E-S: 2110–2120 MHz, 7145–7190 MHz, 34.2–34.7 GHz
 - S-E: 2290–2300 MHz, 8400–8450 MHz, 31.8–32.3 GHz
- Telescopes on the ground operating in the HF and VHF radio bands (50–250 MHz); and
- Radio telescope in the Shielded Zone of the Moon (far side, 10–250 MHz) eventually.

